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Procedia Chemistry 19 (2016) 217 – 221

Procedia
Chemistry

5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015

Welding Investigation and Prediction of Tensile Strength of 304 Stainless Steel Sheet Metal Joint by Response Surface Methodology

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Abstract

This study deals with an investigation of welding behaviour of 304 stainless steel sheet metal in term of joint strength and microstructure. Composition analysis of the stainless steel plate and ER308 filler rod was performed using X-ray fluorescence and SEM-EDX. Tungsten inert gas (TIG) welding was done on SS 304 2B plate with thick-ness of 1.2 mm in Coraza Systems Malaysia Sdn. Bhd using a KADEYOU machine. Response surface methodology (RSM) was employed to develop mathematical relationships between the welding process parameters (i.e, welding current, filler size and flow rate of the shielding gas) and the output variable of the weld joint (ultimate tensile strength) to determine the welding input parameters that led to the desired weld quality. Comparison between measured and calculated results was in good agreement indicating that the developed models can predict the responses adequately within the limits of welding pa-rameters being used. High welding current (50A) cause microstructure become finer and increase in tensile strength while low current (30A) caused root of the metal plate not weld completely which weakened the joint (724.84 MPa and 718.33 MPa, correspond-ingly). The smallest filler (1.6 mm) was good for tensile strength (745.96 MPa) com-pared to the largest filler (2.4 mm and 720.90 MPa strength) because high heat energy used to melt the large filler also overheated the metal base that cause crack formation. High flow rate (14 cfh) caused tensile strength to drop (738.49MPa) due to the turbu-lence in the molten metal compared to the lowest flow rate (10 cfh and tensile 756.75 MPa strength).

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Peer-review under responsibility of School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia

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Keywords: Welding, aluminum alloy, tensile strength

1. Introduction

In Coraza Systems Sdn. Bhd, TIG is frequently used to weld SS304 2B thin sheet metal, due to its good resistance to rust and corrosion. Tungsten inert gas (TIG) welding is the process of joining different metal with high quality weld bead by electric arc generation between electrode and work piece in the presence of inert gas. Welding operation parameters for thick and thin (thickness less than 2 mm) sheets of stainless steel are different since heat dissipation for both falls in the different ranges. Thus one should consider different rate of thermal expansion/shrinkage, size of weld pool, cooling rate and aesthetic appearance. To weld this sheet metal, welding parameter should be selected carefully. Establish research, results show that the increase of welding current and the decrease of welding speed bring about the large amount of heat input in the welding pool and the enlargement of width and deepness of the welding pool^{1,2}. Welding zone is more hard and brittle in the overheated zone when the welding current is too high³. However, root of welding joint is unwelded when the welding current is lower, so that the strength also will lower.

One case study by Tsung⁴, report that the butt welding shown tensile strength and total elongation properties of high shielding gas flow rate are approximately three times higher than those of the low shielding gas flow rate. Thus, in order achieve the best result of the TIG welding, a set of parameters need to be controlled, which is the currents, filler size and flow rate of shielding gas. A fundamental understanding of several issues related the process is therefore a must to select the best or the most optimum for a specific situation. The Response Surface Methodology focuses on product robustness against uncontrollable influences. The strategy is to find interaction between the linear, square and factor-to-factor interactions are quantified in classical design of experiment. Once determined, the more robust variable and variable levels are available to improve product design. Thus, in this work response surface methodology (RSM) was employed to develop mathematical relation-ships between the welding process parameters (i.e, welding current, filler size and flow rate of the shielding gas) and the output variable of the weld joint (ultimate tensile strength) to determine the welding input parameters that led to the desired weld quality.

2. Methodology

The material used was stainless steel 304 2B with thickness of 12 mm while TIG was used to make the joint. A set of experiment with parameter from the TIG welding machine, which is the current, filler size and flow rate of shielding was identified by using Response surface methodology. Tensile test was done by using the Instron Universal Testing machine at a constant cross-head speed of 10 mm/min, up to the final failure of the joint in order to measure ultimate tensile strength (UTS) which is taken as the response mention ASTM standard. The model of the RSM is built by using Minitab software by key in the parameter data. As data is analysis by the software, a model is form. The model then will undergoes confirmation test by doing another test regarding to the parameter from model to check the accuracy of the model. For the microstructure evaluation, a cross-section of TIG welding were cut, mounted in epoxy resin, ground by silicon carbide paper and polished using diamond paste, and finally continued by etching with 5% of Ferrite acid. X-Ray fluorescence (XRF) was used for elemental analysis of the metal plate that be used where Scanning Electron Microscope and Energy-dispersive X-ray spectroscopy (SEM-EDX) was used for elements present on the filler metal used in TIG welding. X-Ray Diffraction (XRD) on the other hand was used for phase analysis. The microstructure of the joint were observed using Optical Microscopy (OM) to investigate the microstructure of the welds in details. The hardness of welding was measured by Vickers Hardness (HV).

3. Results & Discussion

An interaction between these three parameters: current, filler size and flow rate, are shown in Table 1. The P value, refer to probability value should less than 0.1 to indicate significance of term to the model. Most of the values showed that the P was less than 0.1. The lower the value of P means that the interaction was better. Small p-values for the filler ($p = 0.012$), filler squared ($p = 0.086$), and filler x flow rate ($p = 0.009$) suggesting these effects are important. In addition, to decide this data model can be used or well enough to be used and fit a statistical model, the values of coefficient of determination (R^2) and coefficient of determination adjusted were evaluated. The values must closed

or not different so much. In this study, their values were 85.98% and 67.96% respectively. Since the difference was not more than 20% the result is considered acceptable.

Table 1. Interaction of parameters and ANOVA analysis

Estimated Regression Coefficients for Tensile					
Term	Coef	SE Coef	T	P	
Constant	2082.94	262.461	7.936	0.000	
Current	-8.97	7.373	-1.216	0.263	Linear Interaction
Filler	-742.51	218.631	-3.396	0.012	
Flow rate	-69.21	36.243	-1.910	0.098	
Current*Current	0.08	0.082	0.939	0.379	Quadratic Interaction
Filler*Filler	102.35	51.177	2.000	0.086	
Flow rate*Flow rate	1.61	1.372	1.175	0.279	
Current*Filler	2.34	1.185	1.977	0.089	Full quadratic interaction
Current*Flow rate	-0.10	0.189	-0.543	0.604	
Filler*Flow rate	16.92	4.720	3.584	0.009	

S = 13.4029	PRFSS = 9256.76
R-Sq = 85.98%	R-Sq(pred) = 0.00%
	R-Sq(adj) = 67.96%

Analysis of Variance for Tensile

The response from the residual surface can be represented graphically, either in the three-dimensional space (surface plots) or in two-dimensional (contour plots) that help visualize the shape of the response surface. Fig. 1 shows the surface plot interaction for the developed model.

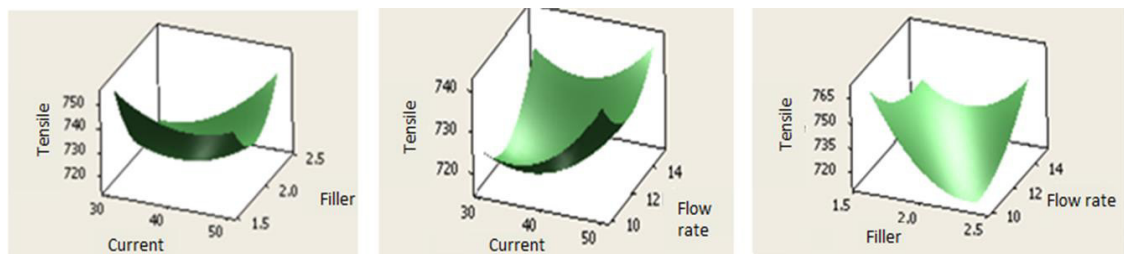


Fig.1. Surface plots for ultimate tensile strength for hold values: current 40 A, Filler diameter 2 mm, gas flow rate 13 cfh

In order to justify the accuracy of model and experimental values, 6 points were chosen from the three different surface contours in Fig. 2. 6 points of welding parameter combination were selected to compare effect of high and low value of one parameter while the two other parameter were kept constant. Using the 6 identified parameter combinations, welding experiment was conducted and tensile test was performed. Table 4.2 shows the value of tensile strength based on the model for each parameter combination.

Table 2 shows the response changes as the three of the control factors (current, filler size and flow rate shielding gas) were varied. The tensile strength of the base material of stainless steel 304 2B was measured as 783.12 MPa while the theoretical tensile strength of the stainless steel 304 2B was 776.27 MPa. Based on the observation, the tensile strength of the weld was higher than that of the base material, fracture occurred at the base material. On the other hand fracture occurred in the welding zone or heat affected zone (HAZ) when the tensile strength is less than the base metal. The experimental data from confirmation test run was almost the same as the model value for tensile strength since the value differs within 10% only.

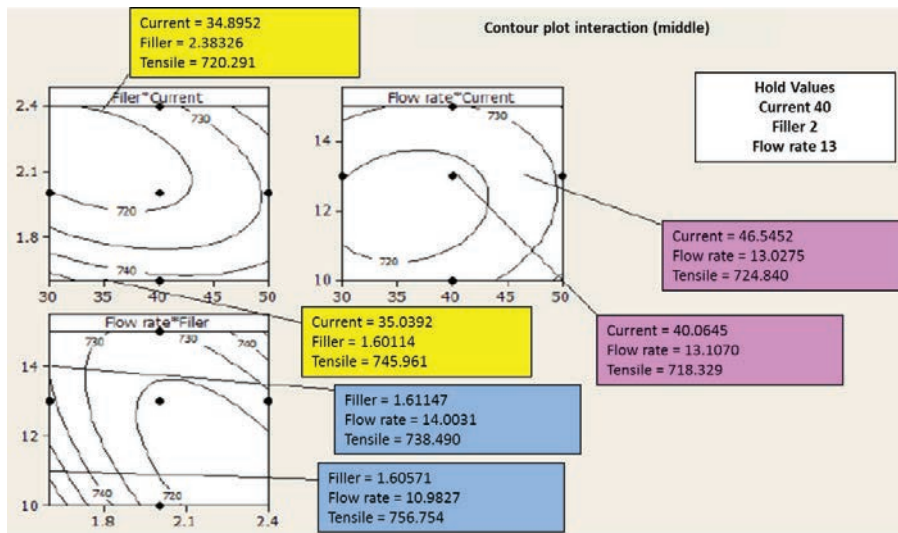


Fig. 2. Contour plots for ultimate tensile strength

Table 2. Tensile strength based on model and experimental data for each of the sample

Sample	Current (A)	Filler (mm)	Flow rate (Cfh)	Mean tensile strength (model)	Mean tensile strength (experimental)	Percent of error (%)
1	35	2.4	13	720.9	725.34	0.69
2	35	1.6	13	745.96	746.680	0.13
3	46	2.0	12	724.84	729.22	0.69
4	40	2.0	12	718.33	796.500	9.79
5	40	1.6	14	738.49	734.00	0.54
6	40	1.6	10	756.75	819.67	8.33

The larger filler gave lower value of tensile test because during welding extra heat required to melt the larger filler was much more than to melt the smaller size of filler metal. As a result, this high heat input will reduce the strength of the welding. This finding is also reported by Jung⁵ on his research on effect of welding heat input on microstructure and toughness in simulated CGHAZ of V-N high strength steel. Tungsten electrodes provide excellent fusion between the filler and base metals; however, great care must be taken not to overheat the base metal. Overheating the base metal due to the high arc current will cause distortion and change of burn through. As a result cracking of the base metal alongside the weld metal is formed on deserved. Under optical microscope, shown in Fig. 3 the crack that forms in sample 1 caused weakening in joint strength.

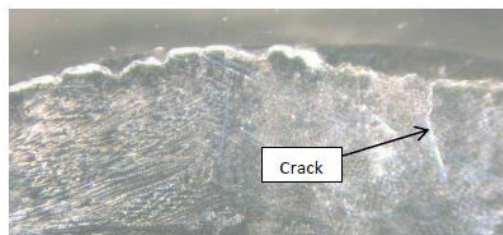


Fig.3. Crack in sample 1

High welding current gave high tensile test rather than lower current. Power (W) is defined as product of voltage (V) and current (A). Hence, increasing the current increased the penetration depth into each alloy (Watanabe, 2007).

Higher penetration depth led to more base metals to be melted, together with melting of filler, thus will have higher tensile strength. Experimentally, 46 A exhibited higher tensile strength as compared to the current of 40 A. Higher the current applied, more heat of the weld to be generated, thus increase HAZ region^{6,7} It was found that low flow rate of shielding gas gave high value of the tensile test rather than high flow rate of shielding gas. Increasing flow rate reduces the porosity of the weld and produces a finer microstructure with the result that the tensile strength of the weld increase⁴. However the tensile strength drops when the flow rate was too high. This is due to the turbulence in the molten metal resulted high flow rate

4. Conclusion

With the use of respond surface methodology (RSM), a model to predict the strength of SS304 weld joint was developed. The model accuracy is adequate based on ANOVA and confirmation test. Interestingly, weld current used should be suitable with filler size in order to achieve good joint. High welding current (50A) with smallest filler (1.6 mm) and low flow rate is beneficial for high strength joint since weld microstructure become finer without crack.

Acknowledgement

The authors would like to thank Universiti Sains Malaysia (BJIM University-Industry Linkage Grant) for the financial support. Technical support and the use of facilities in Coraza (M) Sdn Bhd are acknowledged. Supervision of Mr. Thanabalan, Mr. Badrul Mohamad, Mr. Zulkifli and welder team are highly appreciated.

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